GRB Science Will Die Without a "*Swift+*"* in The Decadal Survey

or

Prompt O-IR Slopes are Key to GRB Progress & a Vibrant Community

* ~ real-time arcmin GRB Positions (like Swift)
+ *simultaneous* Opt-IR Broad-Band Slopes

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Definitions & Context

- Context: **Long GRBs**
  (unless SGRBs, other transients, explicitly mentioned)

- **PLTS** = **Prompt, Low-energy, Time-resolved, broad-band spectral Shape**
  = measurements throughout Optical to Near-IR (e.g., B to H), during the brightest part of the 20-200 keV ("classical") burst, with time resolution T_{90} / $\Delta t \gtrsim$ a few, such that the broad-band spectrum can be compared to emission mechanism (EMm) predictions.

- EMm = "Emission Mechanism"

Argument Outline

- **PLTS data are the critical, missing info** on GRB emission mechanism, jet physics, and Much More

- PLTS are not available or planned for **any** future NASA mission.

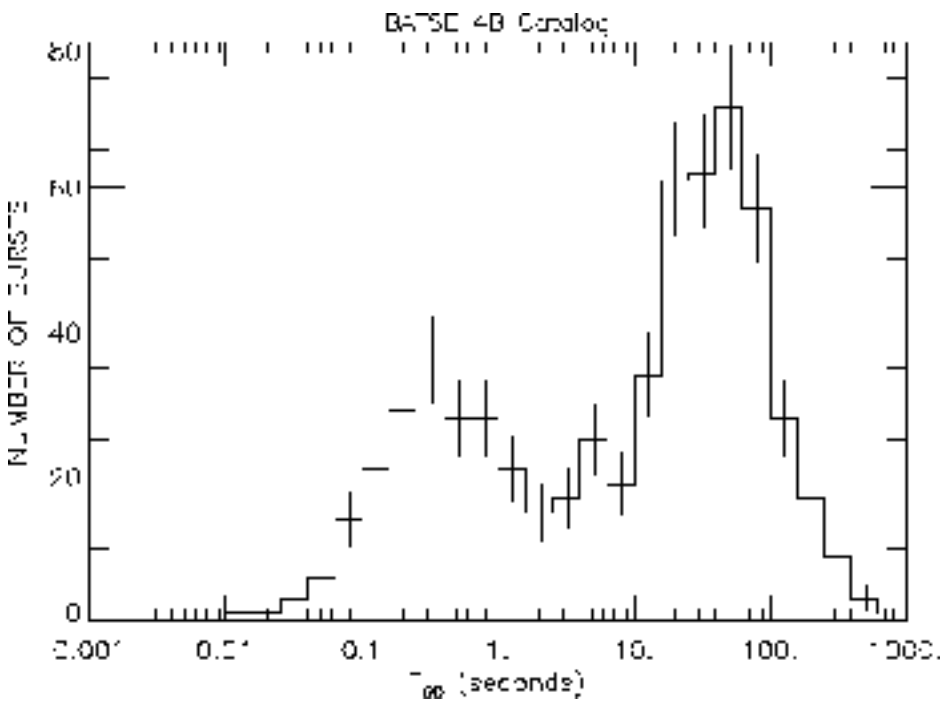
- PLTS require ~arcmin GRB alert positions, allowing ground-based follow-up **by community**
  - **innovative and fast-adapting**
  - **involves largest share of GRB community**

- PLTS EMm, other science **requires spacecraft** instrument
  => **MUST get into the Decadal Survey.**

PLTS = Prompt, simultaneous Low-Energy, Time-resolved spectral shape
EMm = Emission Mechanism

Optical **Prompt** Measurements Difficult & Rare

- Hundreds of GRBs have been observed in X/γ bands.
- Hundreds of GRB ***afterglows***, the interaction of the blast and surrounding ISM, have been observed in almost every band.
  - This is NOT the burst (jet) emission.
- **Prompt** emission $\lesssim 10^2$ s.



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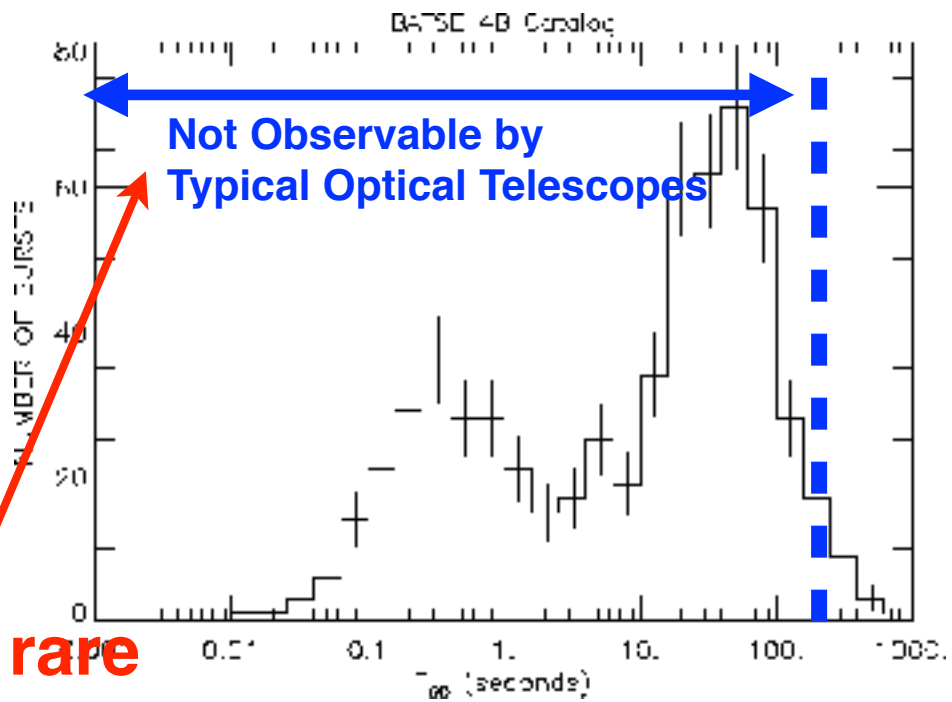

- **Typical optical telescopes require $\gtrsim 10^2$ s to point... prompt optical observations rare**

Why PLTS is critical for GRB **physics**

7.1 Multicolour information for the low-energy spectrum

If multicolour photometry near the optical band exists for the same time interval during the prompt phase, it would provide the local spectral index near the optical band (provided that the extinction correction is properly made). This would be helpful to identify the spectral case the data satisfy. For example, the spectral indices near optical differ by $\Delta\beta = 5/3$ between Cases III and IV, and by $\Delta\beta = 1/2$ between Cases I and III. Unfortunately, this kind of observational information is unavailable for all the time intervals of the optical detection sample we have

[2] Although both works obtained a large R, the inference of R in Abdo et al. (2009) is based specifically on the internal-shock model, while Zhang & Pe'er (2009) gave a more model-independent constraint on R.

Shen & Zhang 2009

considered in Table 1. The hope is that future multiband prompt optical detections may be able to break the spectral case degeneracy and to tighten the R-constraint.

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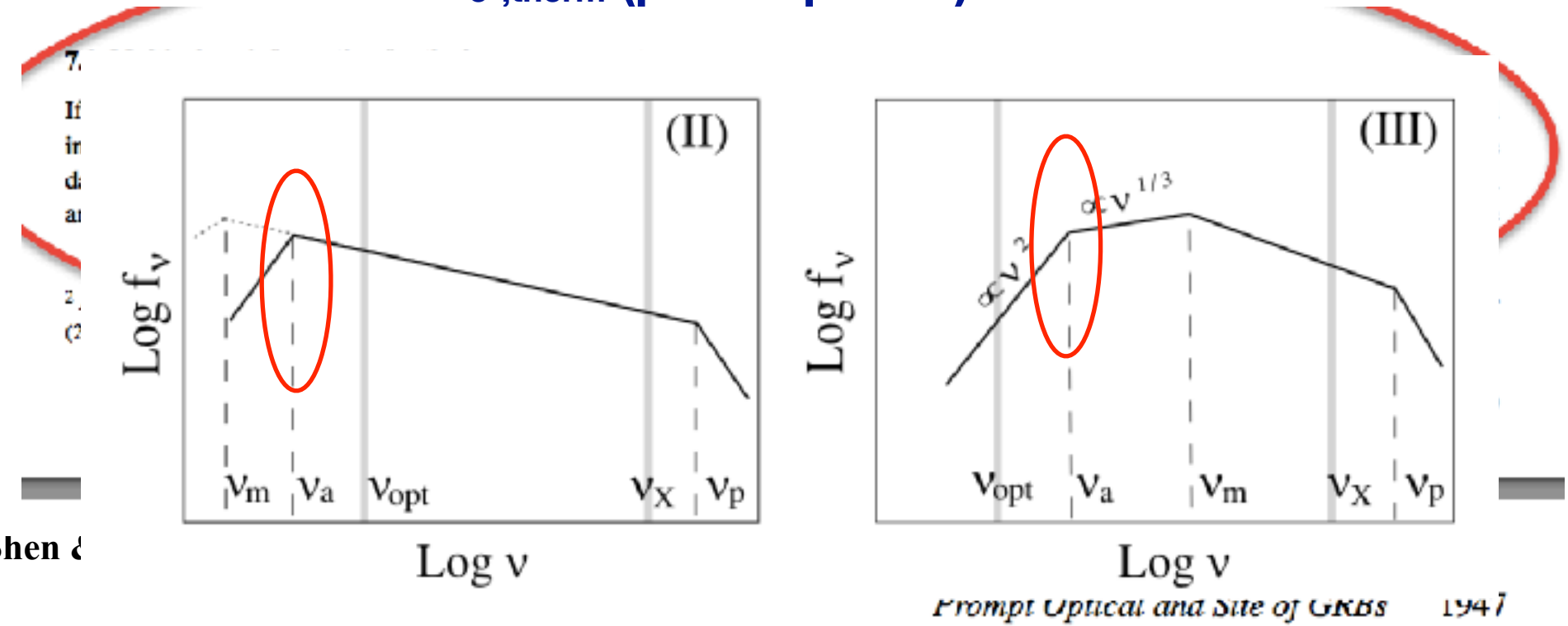

Shen &

Prompt Optical and Site of GRBs 1947

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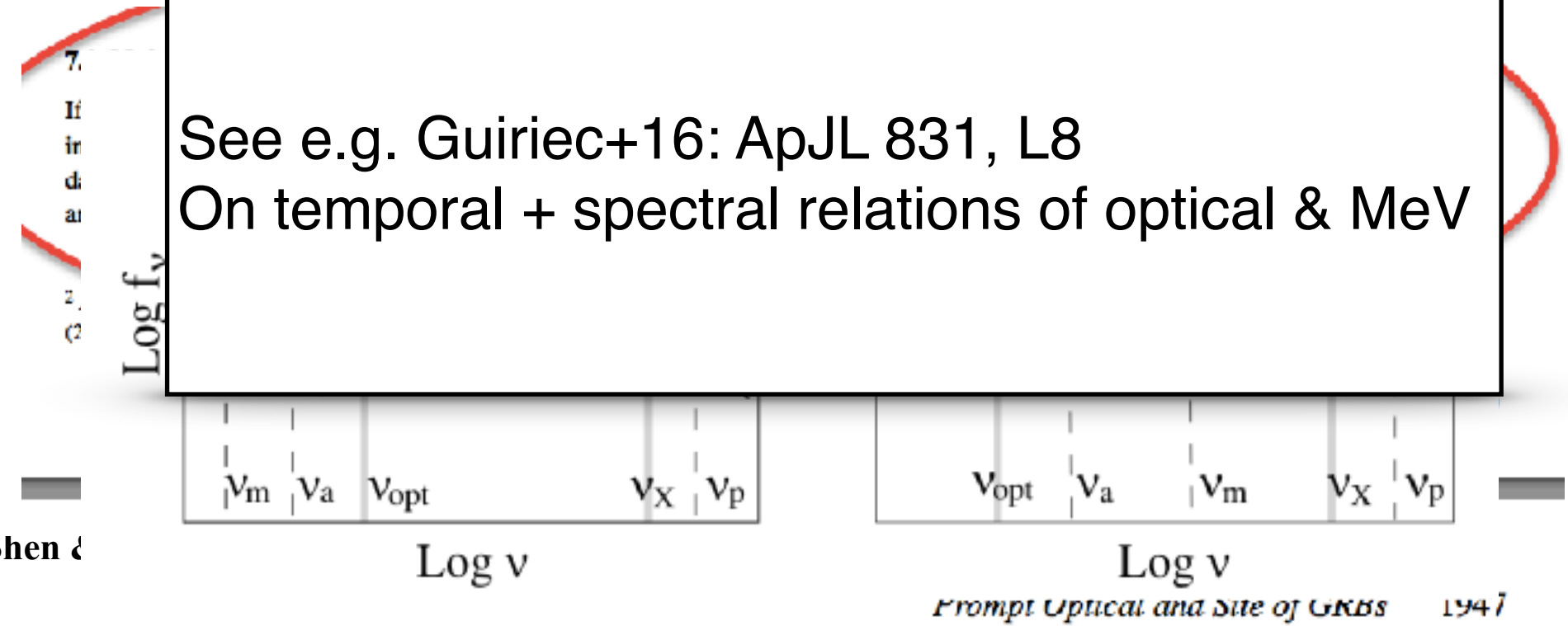
See e.g. Guiriec+16: ApJL 831, L8
On temporal + spectral relations of optical & MeV



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Sig

PLTS is the "Unfinished Business" of GRB Science

- Spectral shape in OIR simultaneous with γ gives rich information, but **has never been measured.**
  ————-> Why not?

- Prompt OIR difficult, but not NEW Tech.
  ————> has not grabbed attention

- To get science, must get into **Decadal,**
  ————>to get some attention.

We **can call attention to Science: mechanism ID, $r_{emission}$, B, good bet for big progress on GRB!**

Straw Man Mission (p.1 of 2)

[1]Grossan et al. 2014, PASP 126,885

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- **Objective: ≥ 36 LGRB/yr, 4+ OIR band PLTS**
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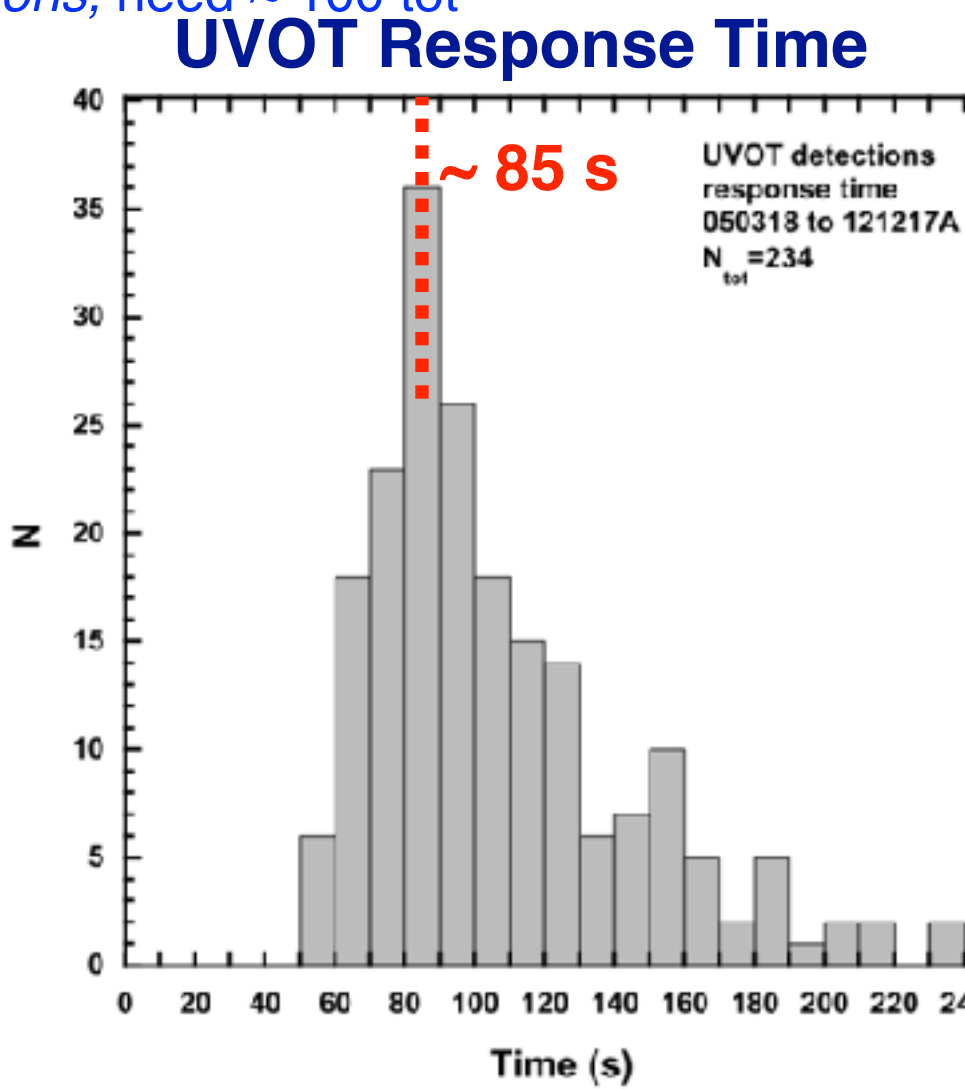

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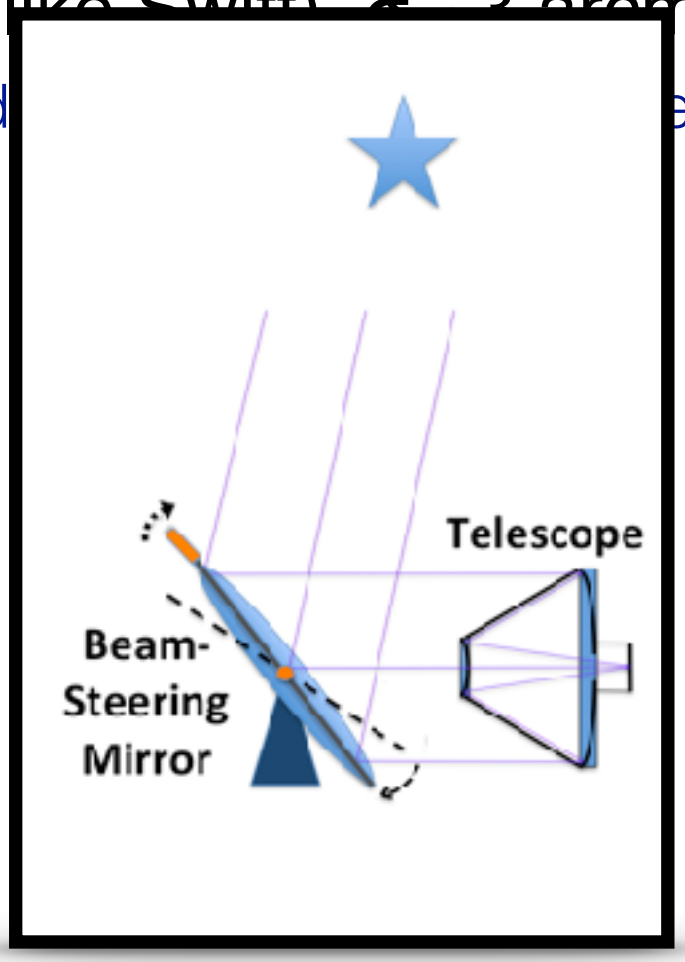

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- OIR: D≳30cm, t_{start}-t_{trig} ≲10s (most of burst), all γ FOV
  -"Swifter than *Swift*", but no new tech:
  - Option1: **Spacecraft points <~ 10 s** (catches most of burst)
  - Option 2: **Steering Mirror Telescope** ([1]Grossan et al. 2014)
    - Note Steering mirror can be used to track; save on s/c pointing
  - ~ 1.5 Sr FOV stationary telescope (like Pi of Sky) – not sensitive (yet), too much background/pix.

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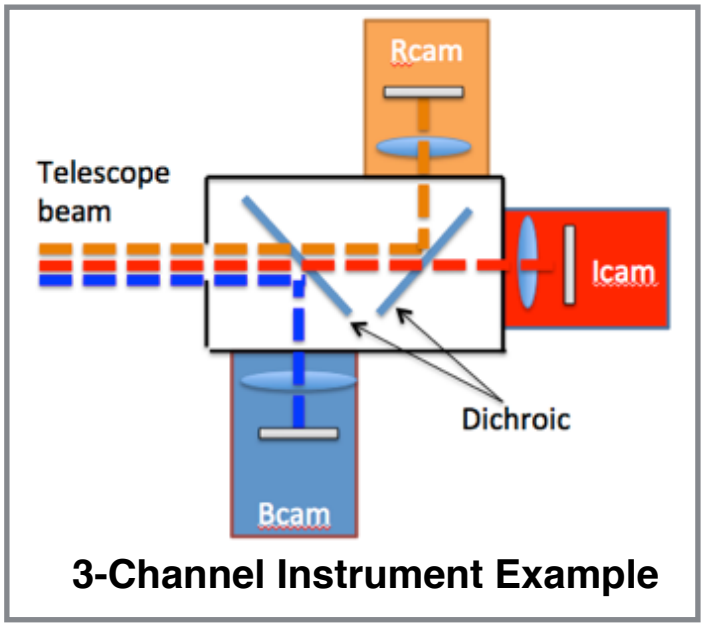
Straw Man Mission (2 of 2)

3-Channel Instrument Example

Straw Man Mission (2 of 2)



3-Channel Instrument Example

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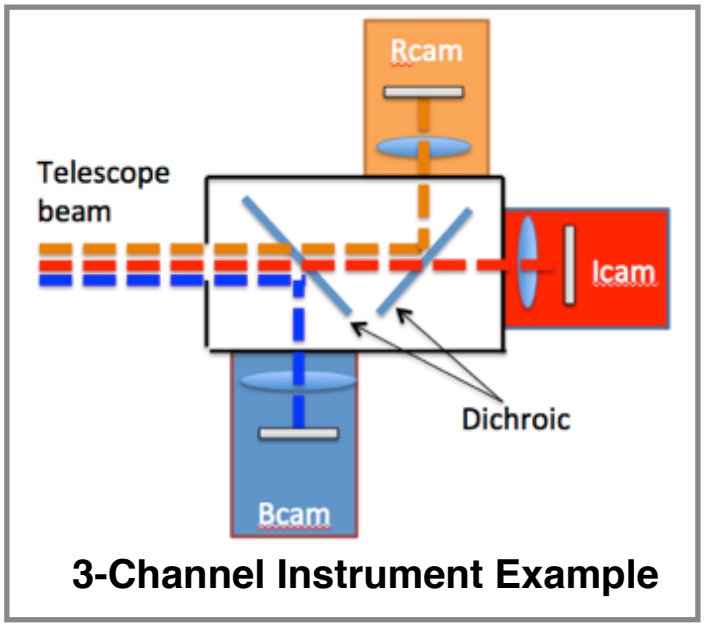
- ~ 4 Cameras for OIR required
  - **Dichroics give *simultaneous* coverage**
  - **Wide spectral coverage to get ν_a;**
    e.g. B-H good (K poor without cooled mirror; note B sensitive extinction indicator, though poor for detection.)
  - 3 channels minimum for finding absorption frequency, **more channels specify more complex spectra.**



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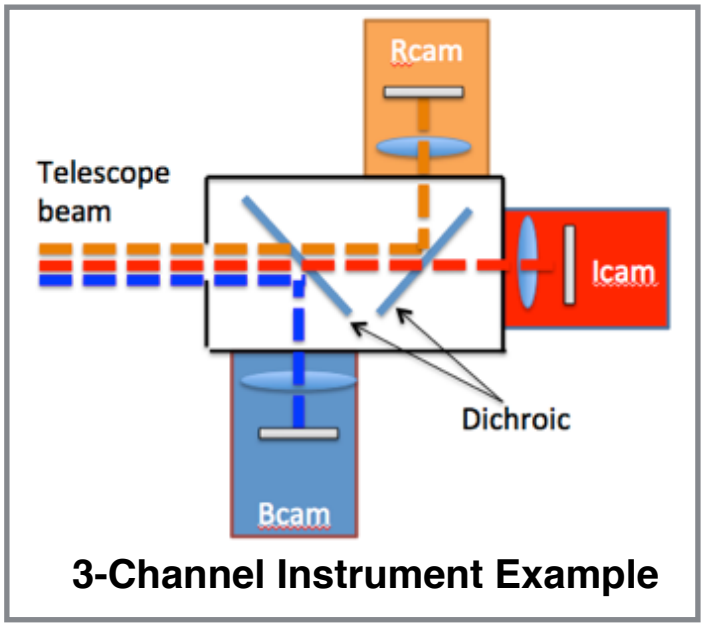

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- Electron-Multiplied CCD (EMCCD) for high time resolution in optical
  - 3-10 frames/s, CCD Q.E. (90%+), no noise penalty
  - **Critical for rapidly-changing phenomenon**
  - **Correlation with γ shows same source (or not)**

Why Not Ground-Based OIR?

- Optical- **Poor Rate**. Clouds Fundamental limit
  - ROTSE III: ~ 3 prompt detects/yr + ~6 limits **(will never get to 100)**
- IR: atmospheric background fundamental limit
  - **IR REQUIRED because most GRB extinguished; new GRB science**
  - **Gnd-based NIR sensitivity requires D > 1 m => too slow for prompt***
- Why not ground follow-up non-Swift GRB?
  (i.e.,**>10 deg² Positions** - Fermi, etc., etc.)
  - require ~ .25”/pix for sensitivity[1] (most GRB), > 10^{10} pix required.
    Read-out every ~1s **not yet practical.**
    Wide field instruments typ. R ≤ 10 mag

*maybe possible, never demonstrated past 0.7 m, requires tech. development

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Why Not Ground-Based OIR?

When *Swift* is gone,
NO PLTS possible
NO PLTS emission mechanism progress
NO ν_a, so no $r_{emission}$, etc.

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   - **polarization** not really the ultimate tool - *fundamentally*, any low polarization value can be explained away by scattering
   - **low-E sensitivity** ≠ high-z GRB (i.e. correlation of γ properties & z has huge scatter, instrumental issues)
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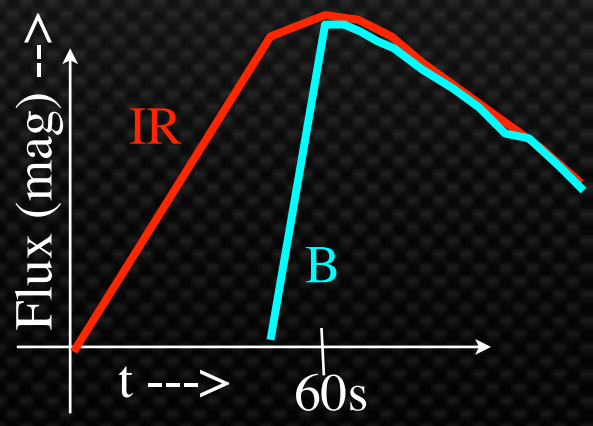
3. Doesn't invigorate community without ~ arcmin positions.

PLTS “More" #1-Dust Evaporation

- LGRB associated with dusty star forming regions

- GRB expected to vaporize dust throughout typical star forming cloud[1,2]
  - Typical cloud size ~ 10's of light sec

- Time-dependent extinction measurement would
  - confirm calculations of dust density, evaporation, probe local environment
  - **Solves excess gas absorption problem -** Too much X-ray absorption for blue, low-extinction afterglow(3,4,5)
- Need time-dependent spectral slope starting earlier than most previous measurements



[1]Waxman, E., & Draine, B. 2000, ApJ, 537, 796

[2] Perna, R., Lazzati, D., & Fiore, F. 2003, ApJ, 585, 775

[3] Galama& Wijers 2001, ApJL, 549, L 209 ; [4]Stratta+04, ApJ, 608, 846

[5]Schady+07, MNRAS, 377, 273; Perley+09, AJ, 138, 1690

More#2- GRB as backlight for high-*z* universe

- (Nearly) Prompt spectra BRIGHT -
  Good for absorption-line mapping @ ultra-high-*z*
  - First measurements (**prompt can be > 5 mag brighter**), farthest GRB:

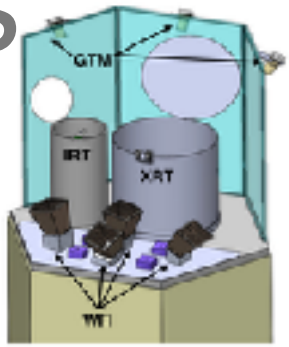
GRB	**z**	**m**[1]
090423	8.2	**K=17.5** @t_0+20 min
080913	6.7	K=20.5 @t_0+26 min
140515A	6.3	J=20.6 @t_0+30 min
050904	6.3	**J=17.5** @t_0+180 min

  - Compare to HUDF objects: spectra **impractical**.

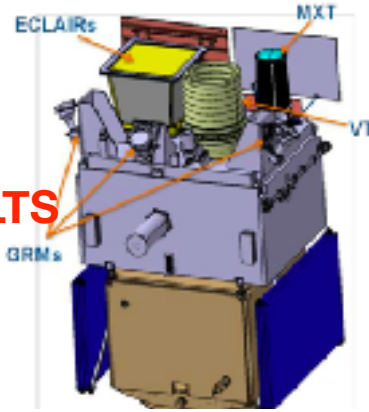
- Onboard positions make (near) prompt spectra possible:
  - **"real time" detection => arcsec positions in ~10-60s**
    TDRSS to GCN < 1s => spectra starting ~t_0+100s now practical

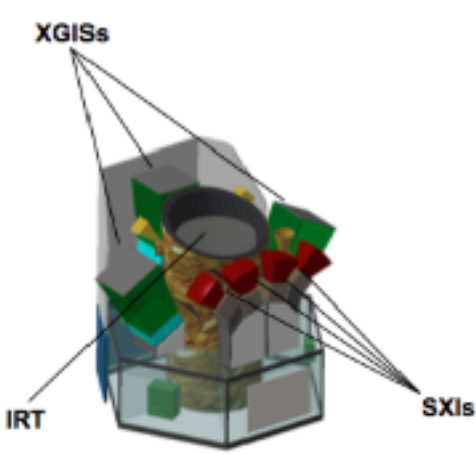
1 - GCN Circulars, referenced from Swift Burst Page; List taken from Wikipedia (spectroscopically confirmed).

NO Current PLTS Missions



- TAP - TRANSIENT ASTROPHYSICS PROBE
  - Now in Probe Mission Concept Study; https://asd.gsfc.nasa.gov/tap
  - 1 deg FOV IRT, but **no serious plan for PLTS**; emphasis lobster optics w/MCP
- SVOM - French-Chinese Mission
  - very much on again-off again for decades
- SVOM 2015 (Cordier et al.2015/2016)[1]
  - VT= 2 bands to 0.9 μm; NOT ENOUGH to get ν_a; **no serious plan for PLTS**
  - Ground-based GWAC 5000 sq. deg. V≤ 16, POOR because…
  - Scaled-back ECLAIRs now up to 14' errors (much worse than Swift)
- THESEUS (ESA) - for ESA Cosmic Visions M5
  - proposed; see https://arxiv.org/pdf/1712.08153.pdf
  - **No plans for PLTS**, just "add-on" NIR telescope





1. https://arxiv.org/pdf/1512.03323.pdf

Conclusions

- Fundamental GRB Science Requires OIR Slopes Simultaneous to Prompt γ emission
  - Emission Mechanism
  - Radius of Emission, Electron energy distribution (Shen & Zhang'09)
- Other Good Science from Same Instrument
  - Dynamic Dust Studies
  - Absorption mapping beyond EOR via near-prompt absorption spectra
- SHGRB and GW candidates **NATURAL** target; arcmin positions => Maximum wavelength coverage via community follow-up.

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-THANK YOU FOR LISTENING-

Extra Slides

GRB emission mechanism

- "Standard" Internal Synchrotron Shock Model[1] (ISS; log slope +1/3)
  - Equipartition *roughly* gives correct ν f_ν peak energy[(2)]
  - **Most observations inconsistent; may be unphysical[(1)]**

- Either multiple or variable slopes, components/mechanisms required
  - Log Slopes 20-200 keV have broad distribution, ~0.1±0.35
  - Thermal photospheric component pretty clear in some GRB
  - Extrapolation to optical off (+ or -) by orders of mag

- More recent fits explore Maxwellian vs. PL e^- N(E), *still* disagree whether synchrotron acceptable or not. (3)

- Conclusion: heterogeneous properties yield **no consensus, we're stuck.**

1. Rees & Me´sza´ros 1994, see Piran 2005
2. Ghisellini, Celotti, Lazzati, 2000 MNRAS 313,1 . Note they state that correct time-averaging gives slope -1/2, inconsistent with observations.

2. Burgess arXiv 1705.05718 vs. Axelsson & Borgonovo 2015 MNRAS447,3150; Yu et al. 2015 A&A, 583, A129

110205A-260s - Guiriec Model

- Simul. UVOT (very rare!) resembles MeV
- NO optical **spectral** data here!!
  - Fit looks good, But …
    -huge gap to optical!
    -huge band from just one point in optical!
- -> Need optical Spectrum for better fit.
- Need MORE examples.

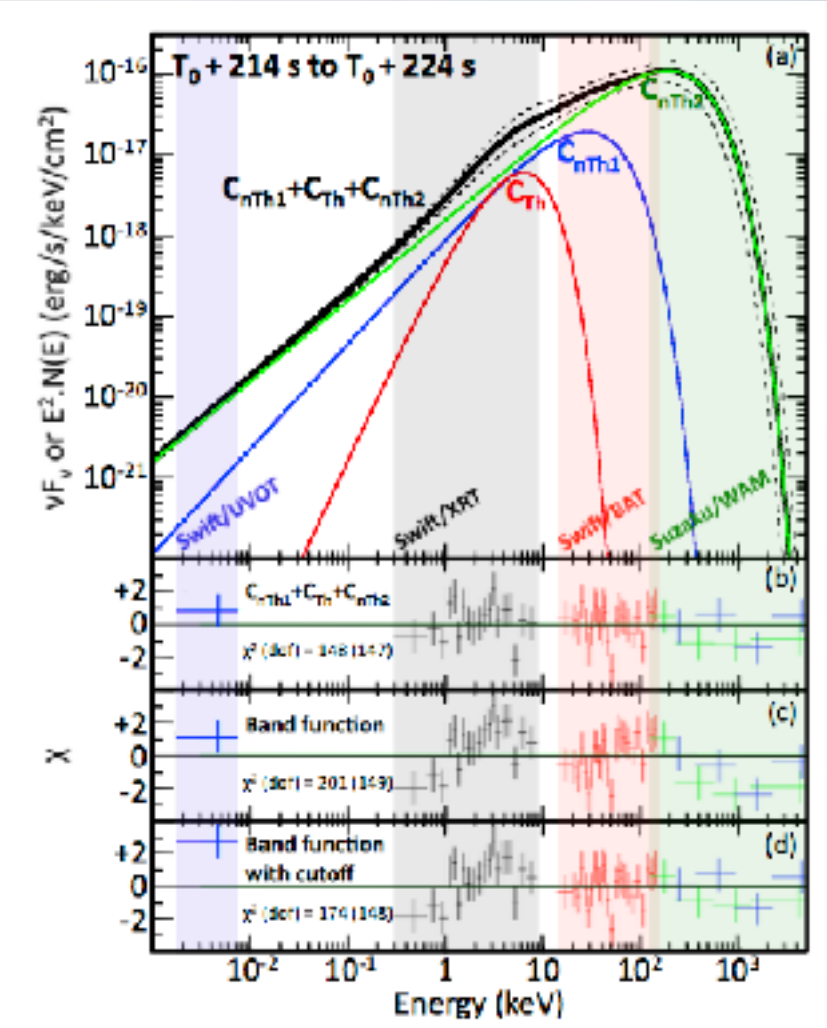


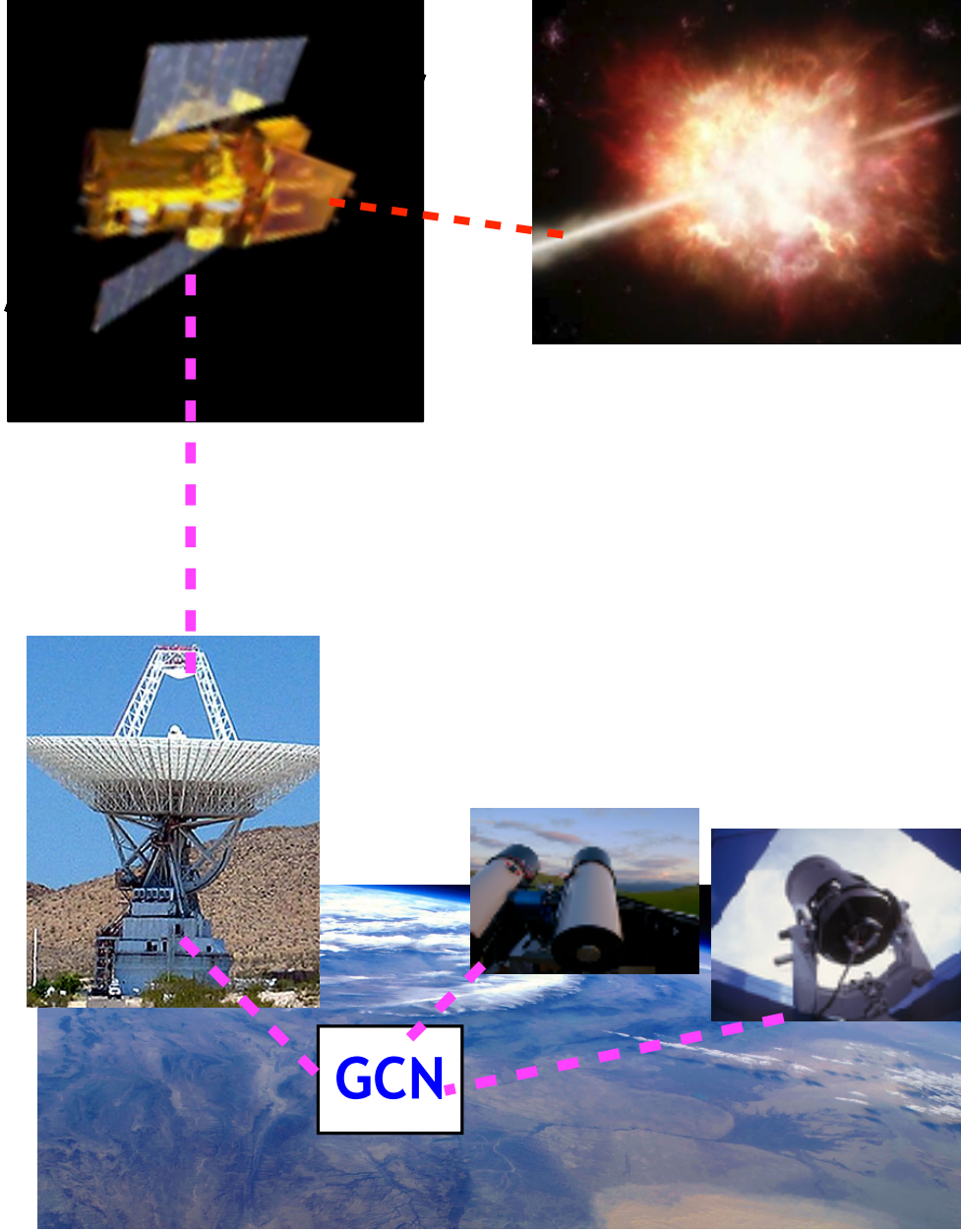
FIG. 2.— a- $C_{nTh1}+C_{Th}+C_{nTh2}$ fit to the four instrument data from T_0+214 s to T_0+224 s (solid black line) with the 1-σ confidence region (dashed lines); b–d- Residuals of the fits using $C_{nTh1}+C_{Th}+C_{nTh2}$ (b), a Band function (c) and a Band function with a high-energy exponential cutoff (d). The energy channels have been combined for display purpose only. The resulting χ^2 values of the fits are also indicated together with the number of degrees of freedom (dof).

Guiriec+16: ApJL 831, L8; https://arxiv.org/abs/1606.07193

Swift

- Revolutionary; too many successes to list …
- Coded Mask γ camera, focusing X-ray and UV-Optical telescopes
- Many *z* via follow-up
- Many, many light curves
  - X coverage: t=0 to months in X
  - Other bands: t= ~100 s - months (mostly) afterglow

    ~arcmin γ positions allow unlimited community follow-up

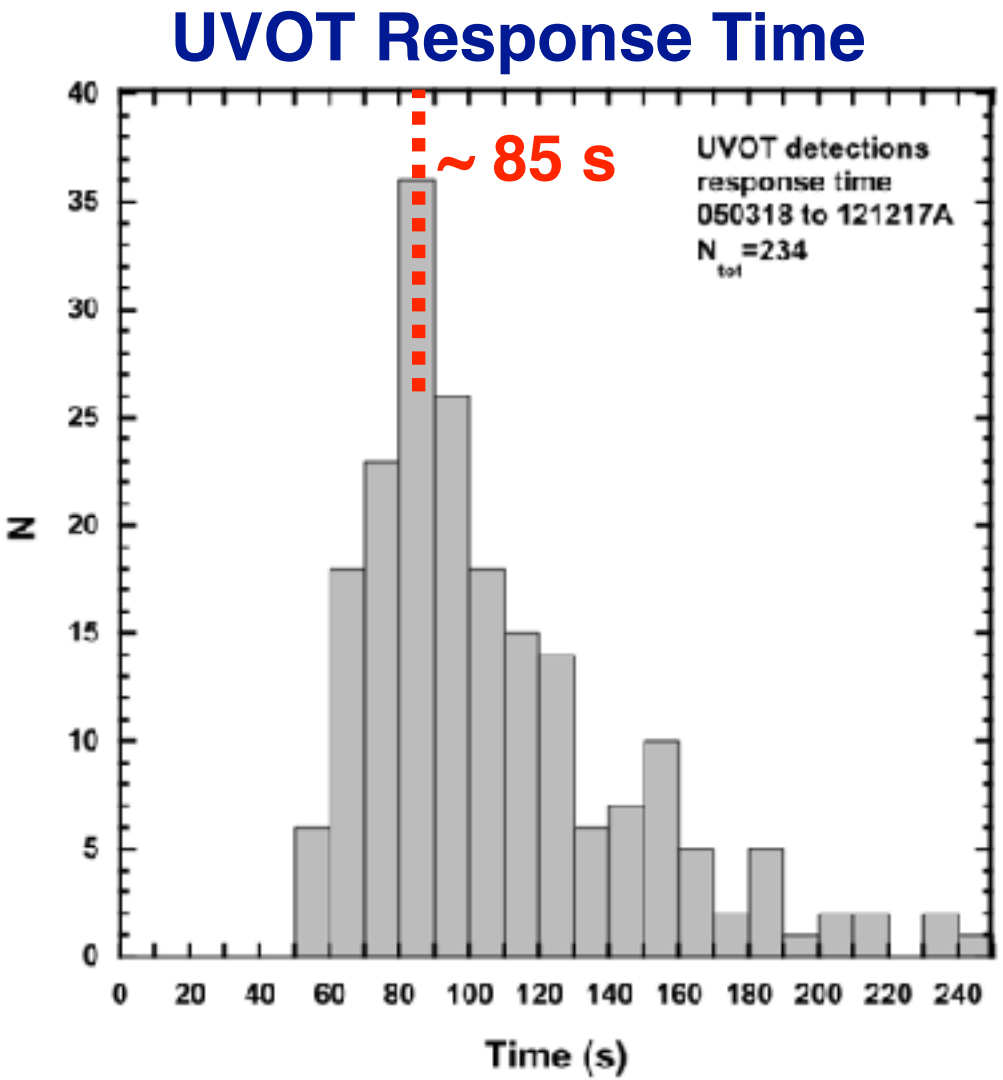


Why Re-do *Swift*?

- UVOT (based on OM to save time, money) was in the wrong wavelength band
  - Extremely poor QE (< 20% in optical)
  - High time resolution not delivered
  - Most GRB are extinguished[1] - UV was the wrong band

- Swift wasn't Swift Enough
  - Typical UVOT response time ~ 85 s but typical duration ~60 s.

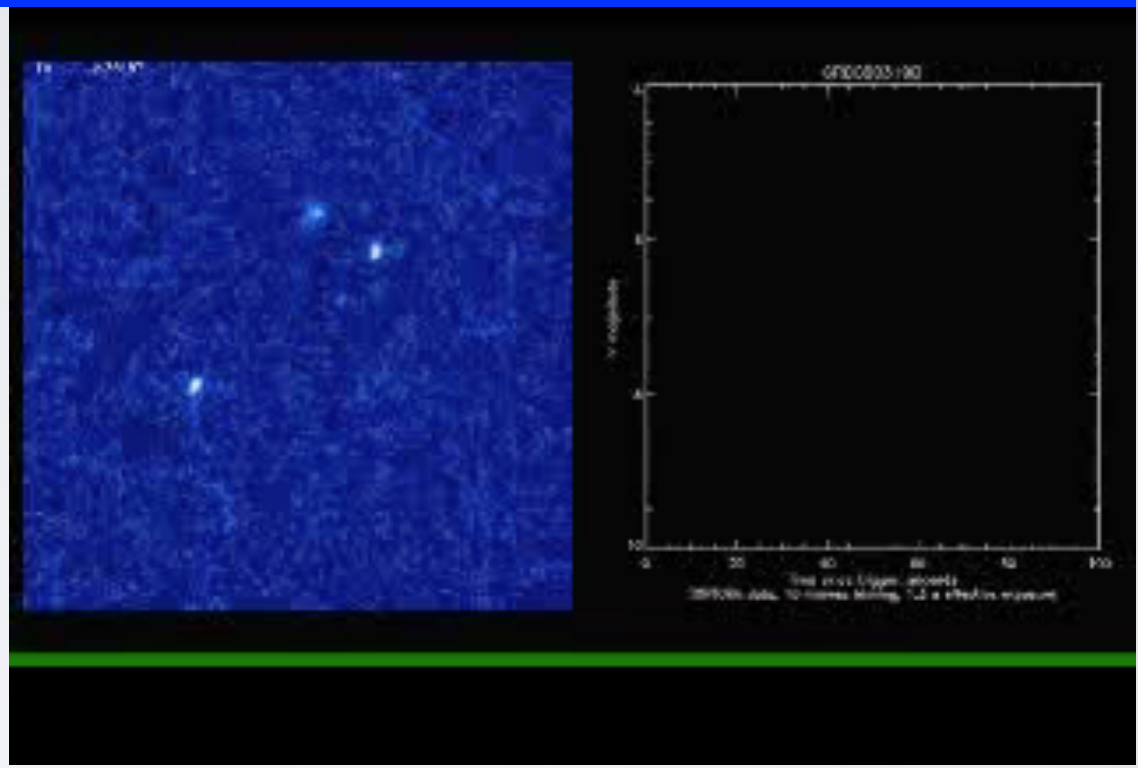
- UVOT was single channel (filter wheel)
  - **No Prompt OIR Spectral Measurement (Still!)**



Current Prompt Optical Observations

- Conventional Telescopes Too Slow
- Wide-Field Instruments
  - **Great Successes! (e.g. Pi of the Sky, Raptor)**
  - **LIMITED SENSITIVITY~ 10th mag**
- Medium-Field *Fast* instruments
  - **Great Successes! Polarization measurements!**
  - **Limited Sensitivity -**
    - e.g. ROTSEIII - 45 cm - R ~ 16.9 mag 10 s ~ 3/ yr.
    - e.g. MASTER-NET - 40 cm - 12-14 mag 10 s w/polarization
  - **NO OPERATIONAL SIMULTANEOUS MULTI-COLOR INSTRUMENTS**
    - **Note that filter wheels are useless for this rapidly-varying source**

Best Prompt Light Curve: 080319B



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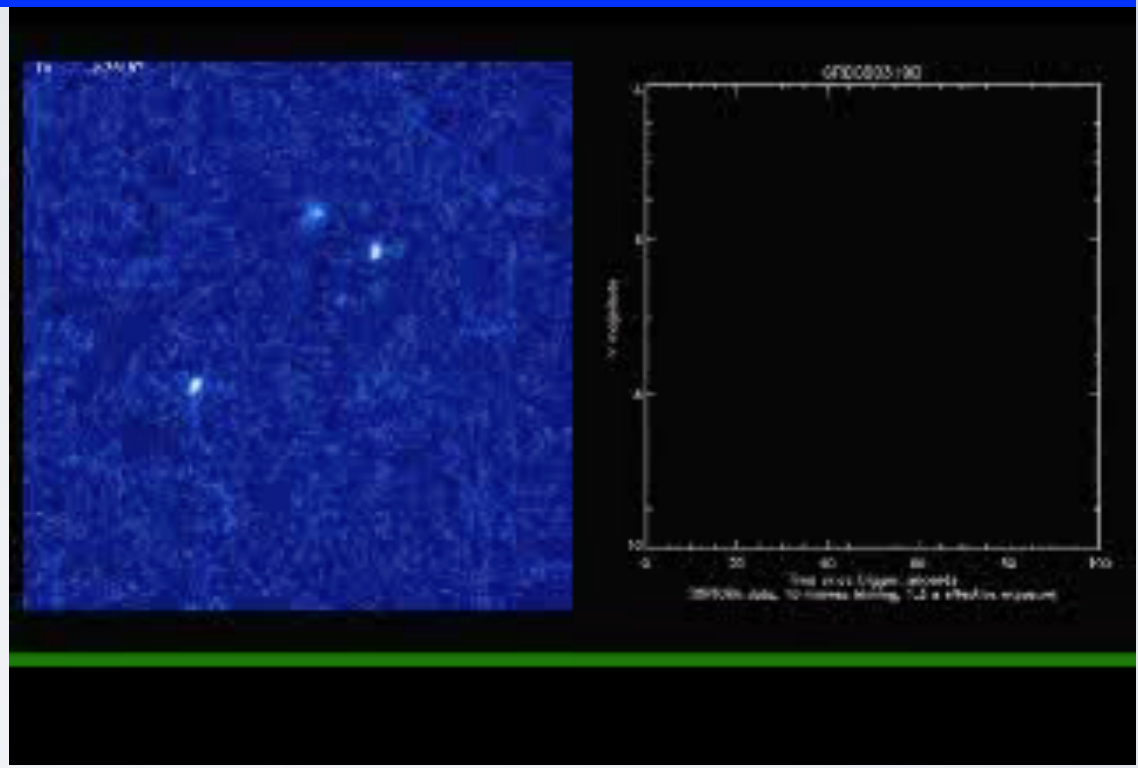

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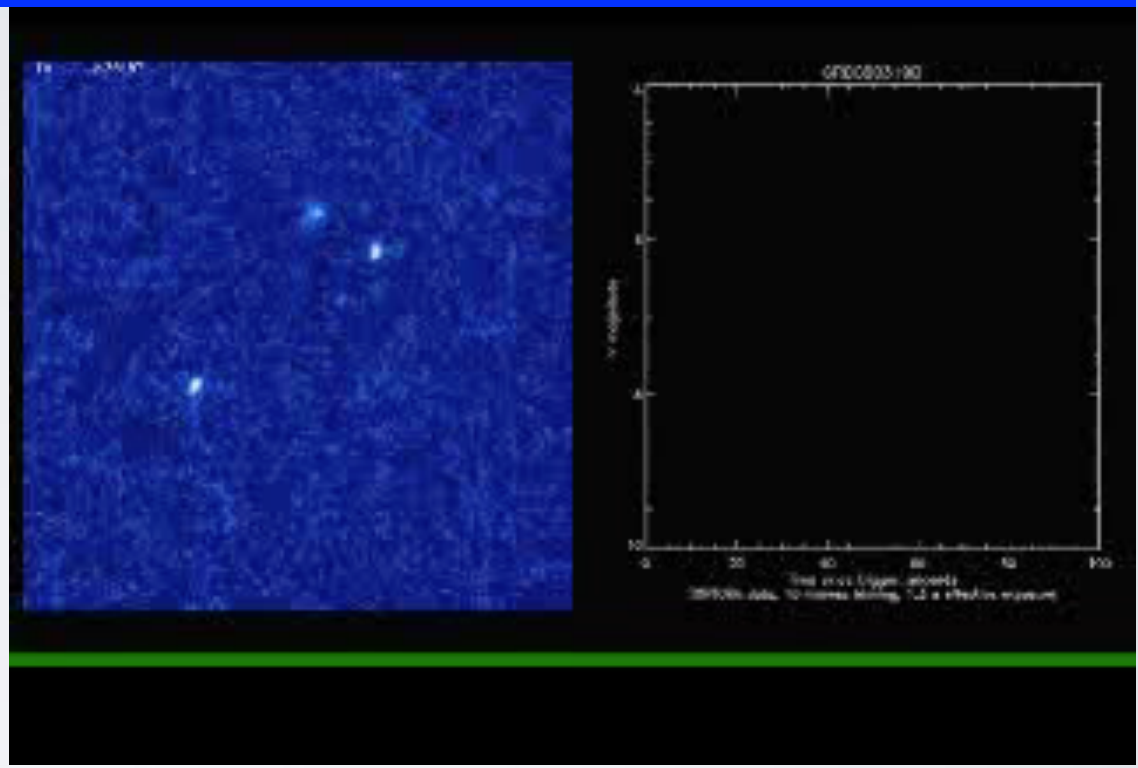
- 080319A was in same part of the sky just before, so many instruments were open, observing
  - Lucky! Prompt optical emission finished in ~ 100 s
    - **most telescopes cannot open or point in less than minutes**.



- Incredibly Bright!
  - Nearly 5th mag!
  - **Amazing light curve by TORTORA, vidicon instrument (Molinari+06)**
  - **Detection by Pi-of-the-sky**

Above instruments not sensitive to any but most exceptionally bright bursts.

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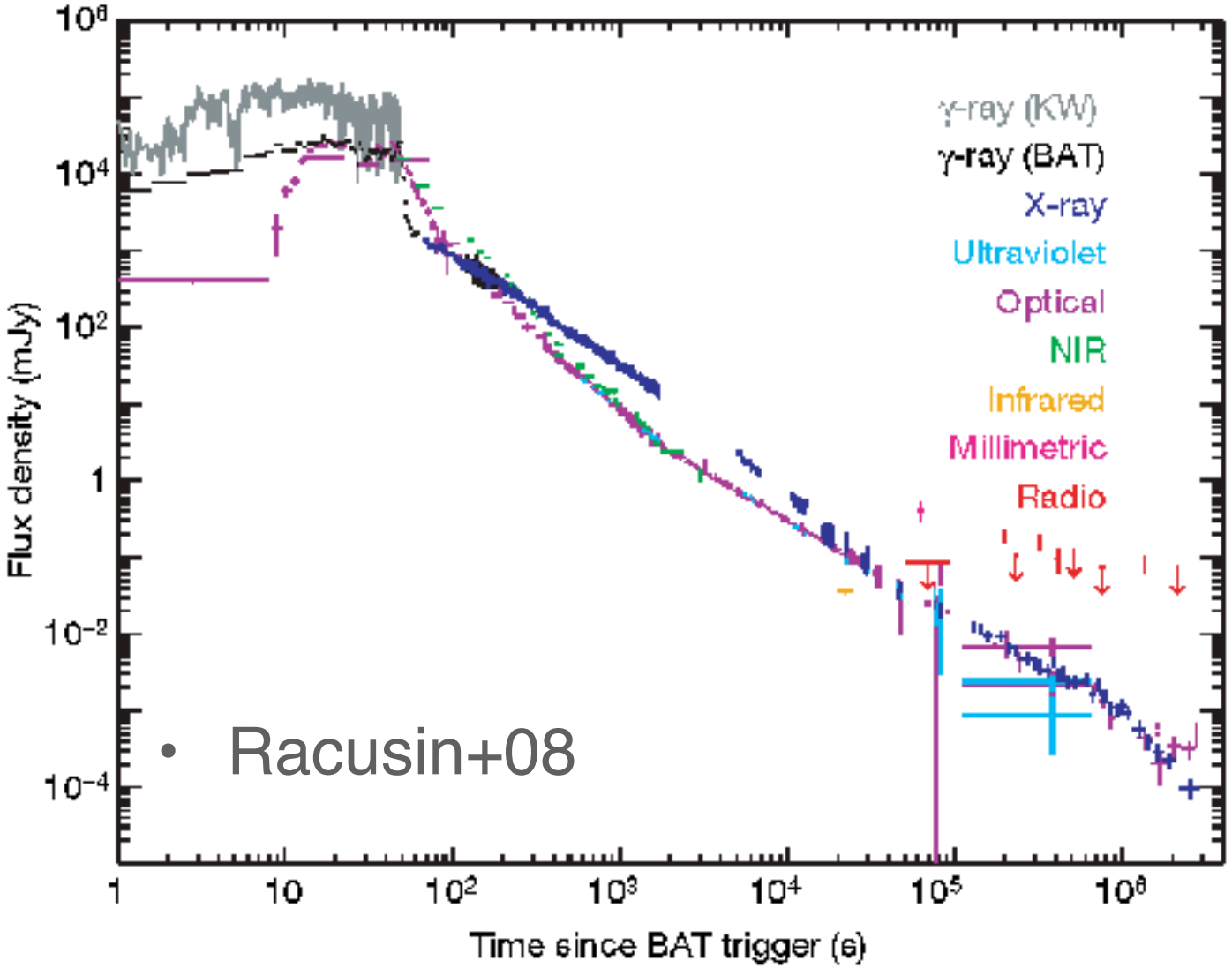
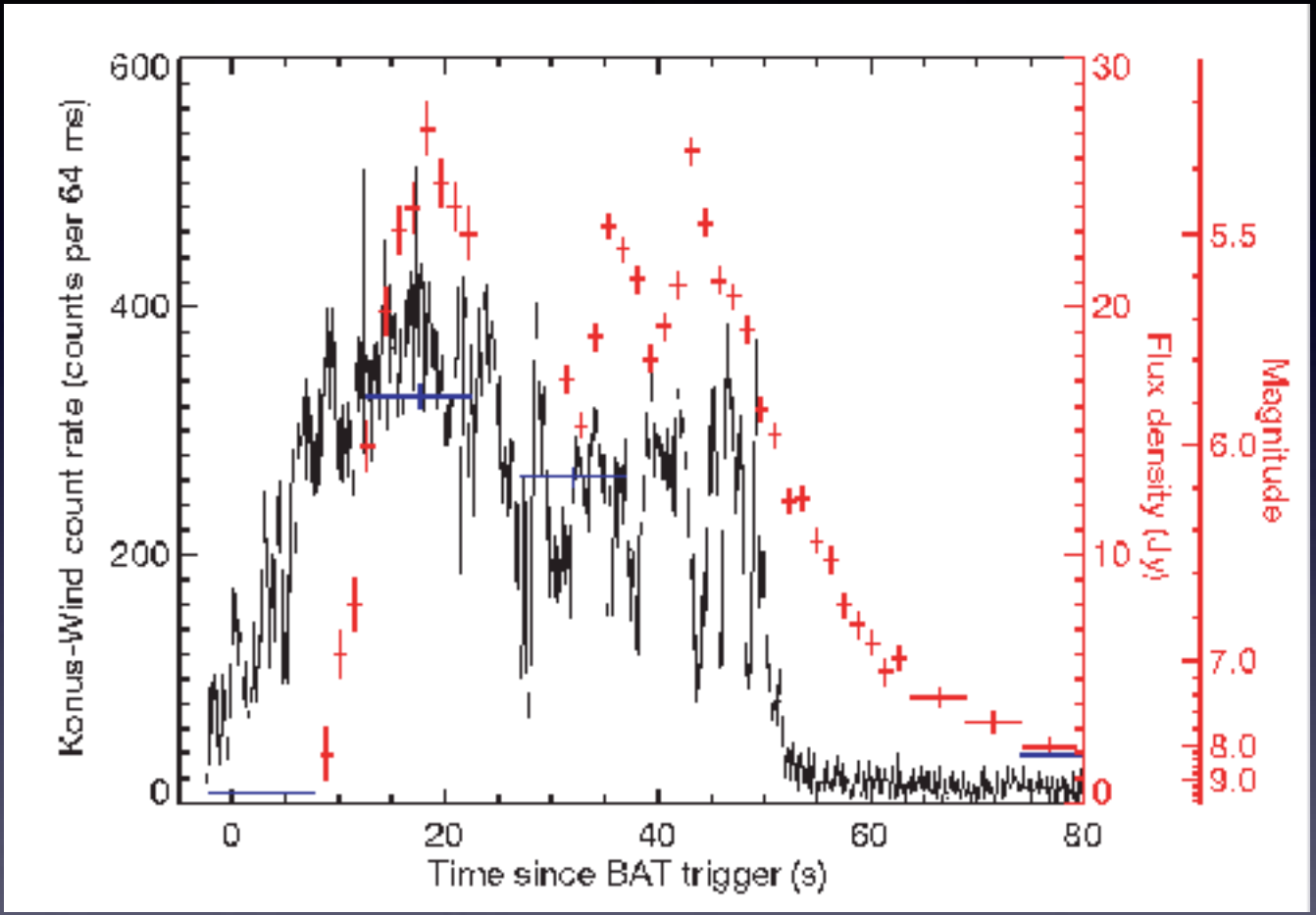
080319B Light Curve



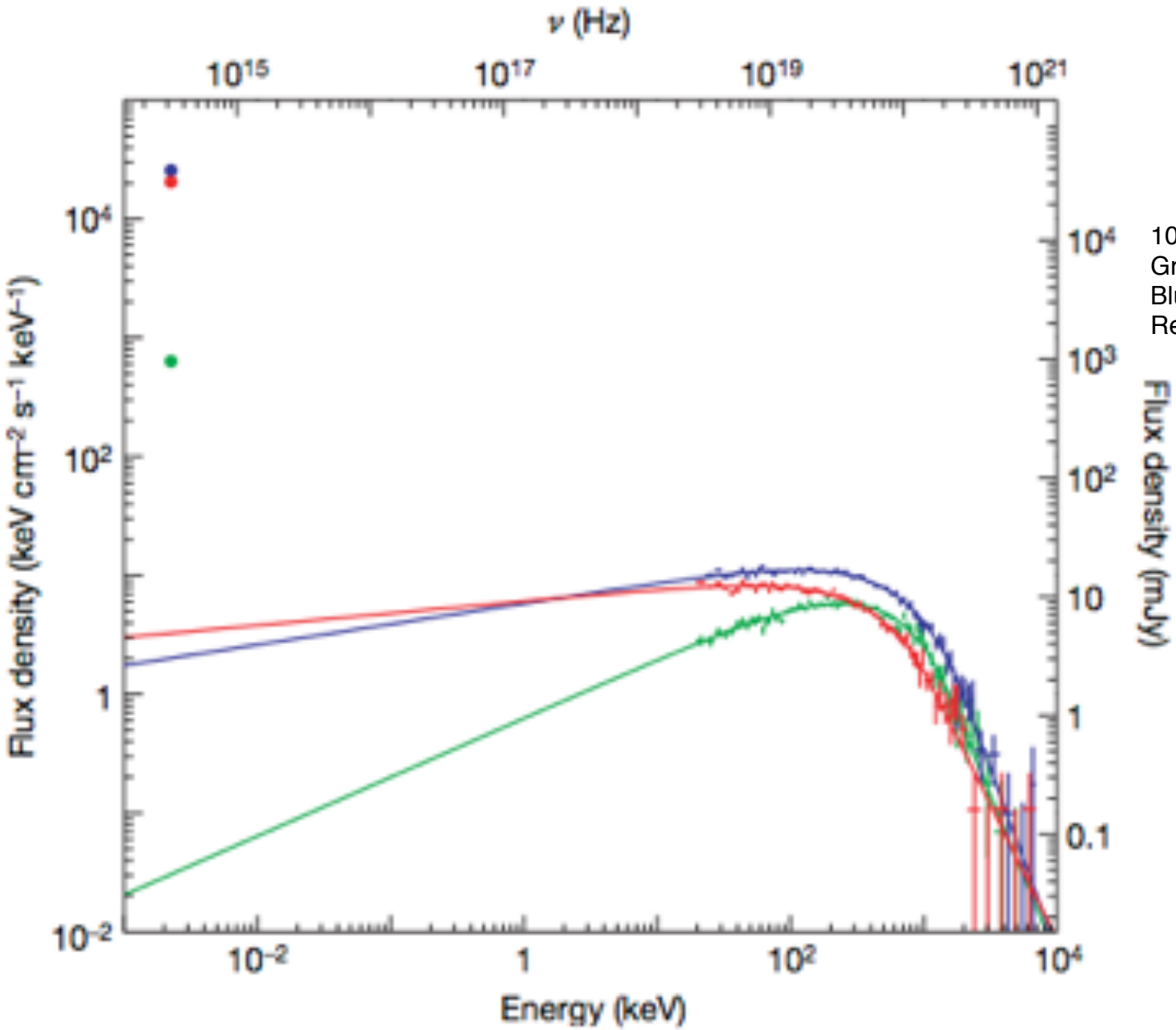
- Two-component jet proposed, 1 ($\Gamma \sim 10^3$) for ultra-bright prompt optical, second (low Γ) for afterglow, consistent with decay slope breaks and mis-matches

Time-Resolved Optical Data



Such rich data available in NO OTHER burst in > 10 years of *Swift!*

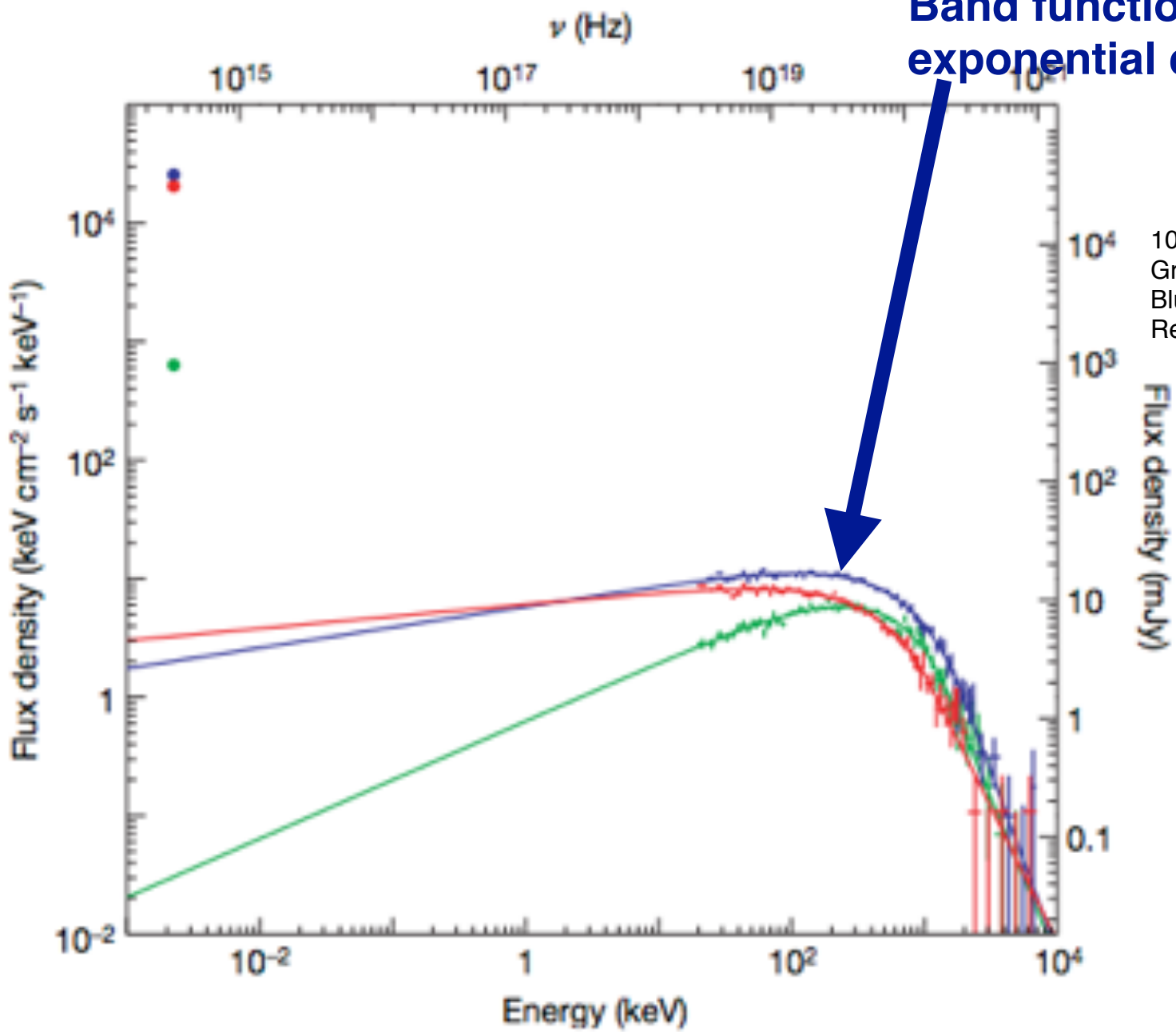
Spectrum in 3 time periods



10 s integration about:
Green: T0+3 s
Blue: T0+ 17 s
Red: To+32 s

Spectrum in 3 time periods

Spectra Commonly fit by Band function, 2 PL with exponential cutoffs.



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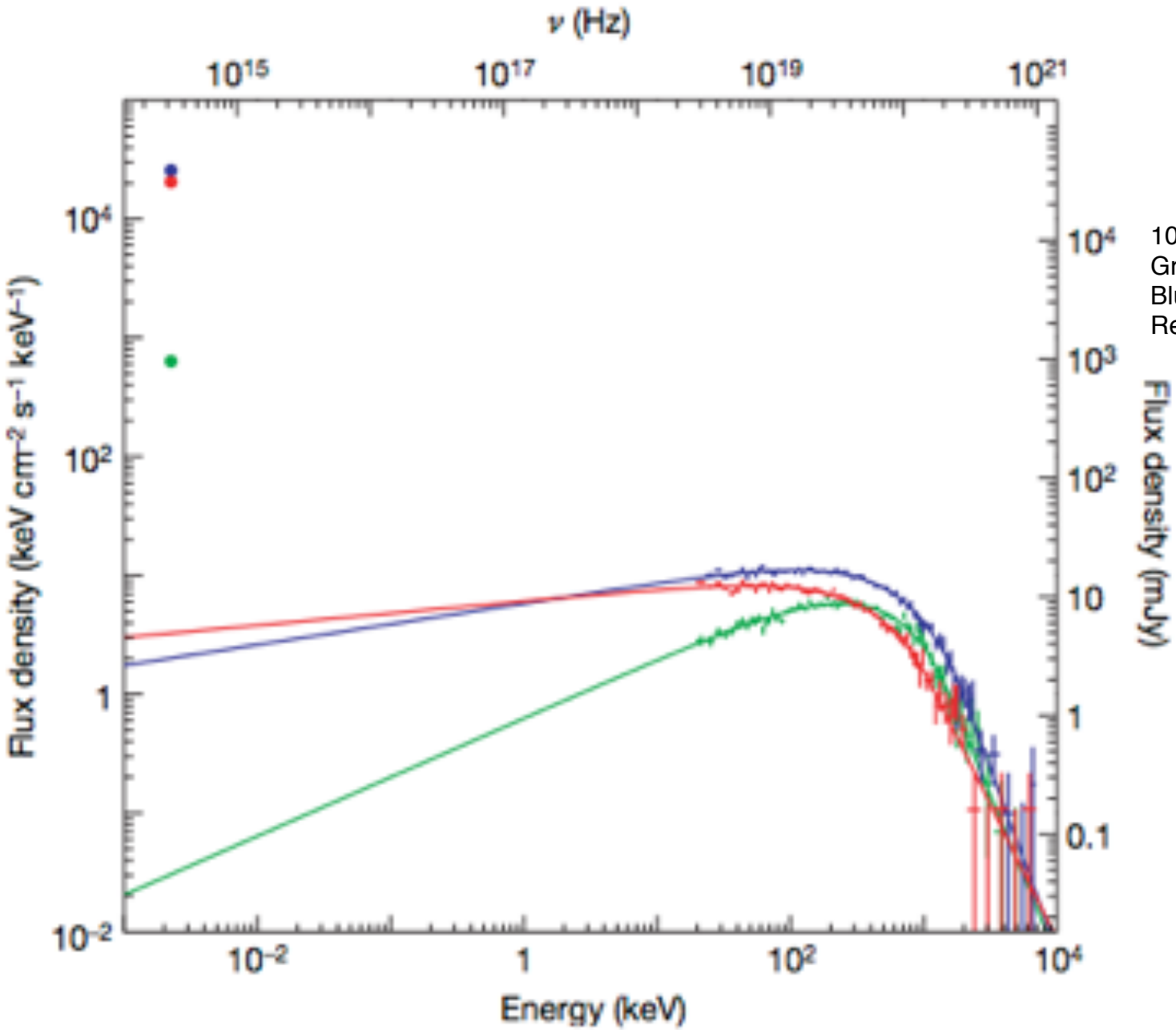

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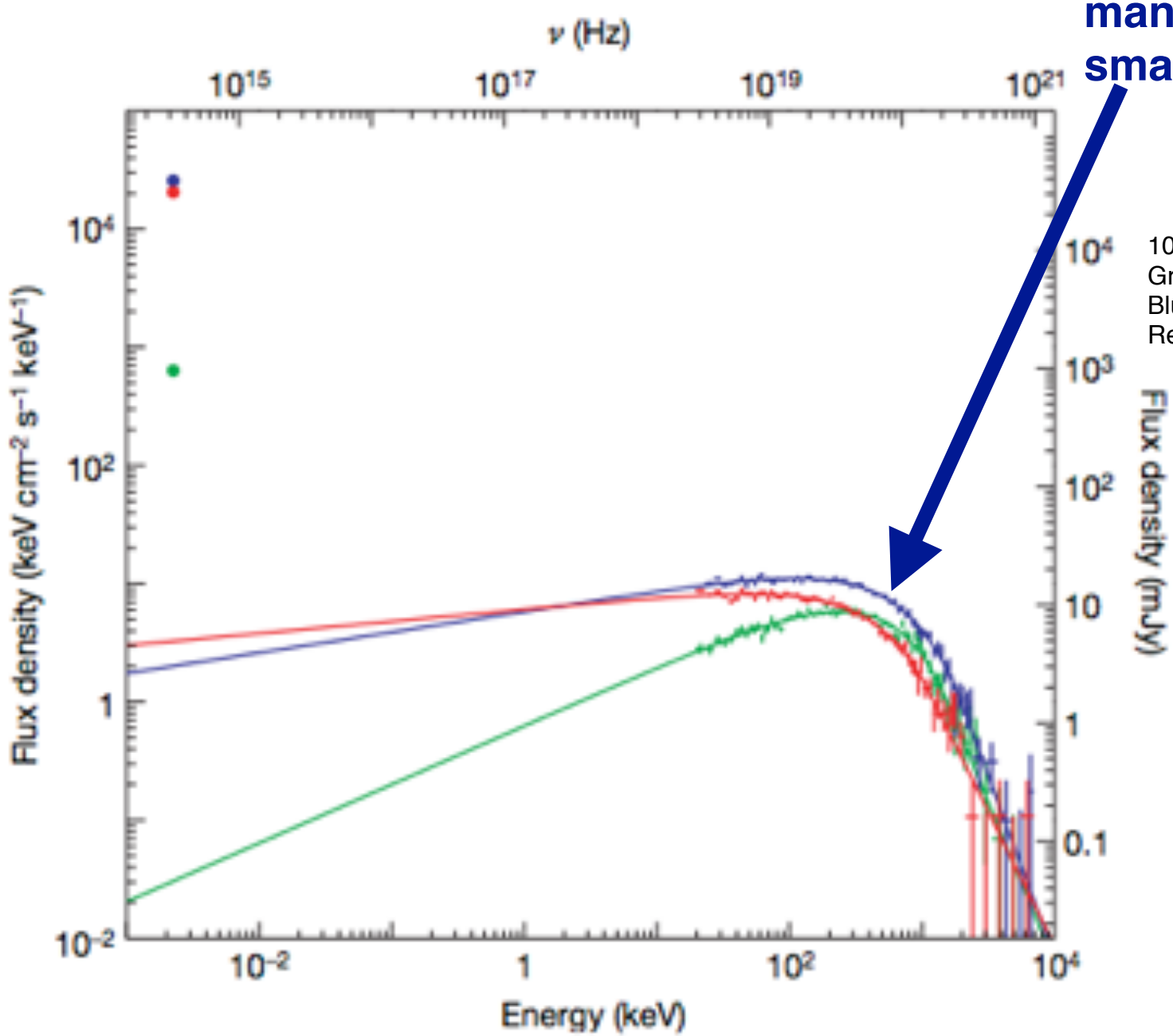
Spectrum in 3 time periods

Rich data here; many channels, small errors



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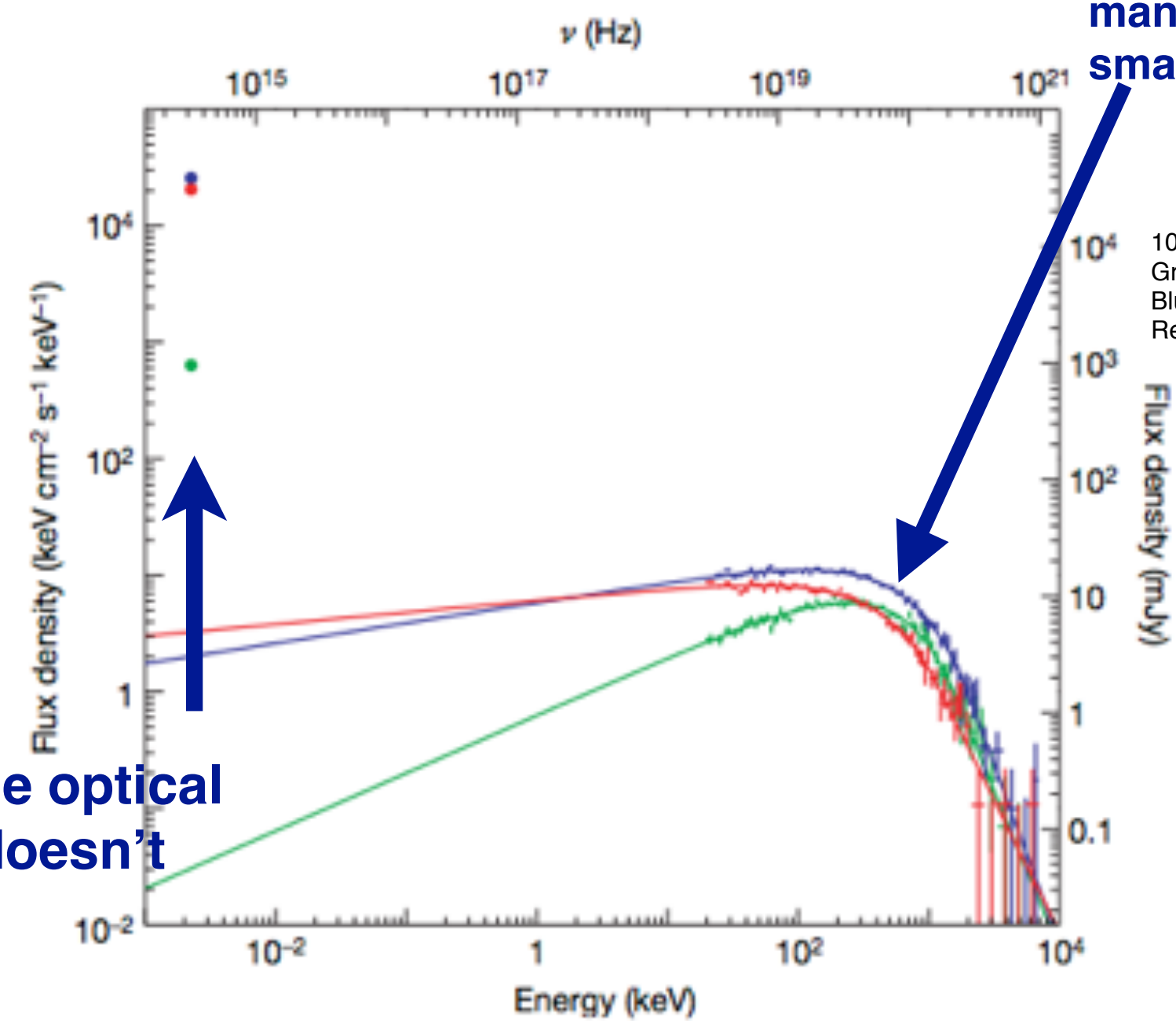

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Just one optical point, doesn't fit!!!

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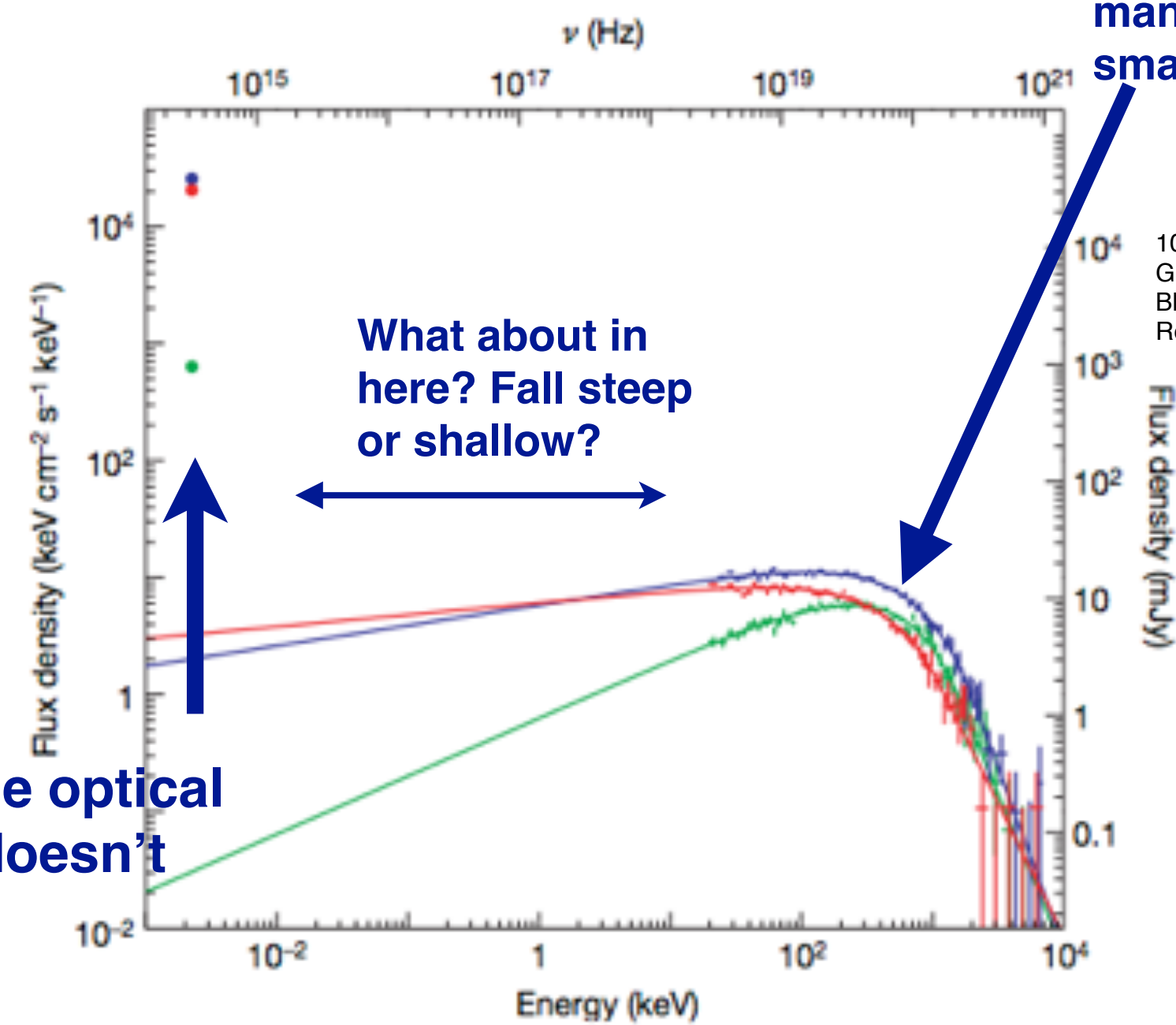

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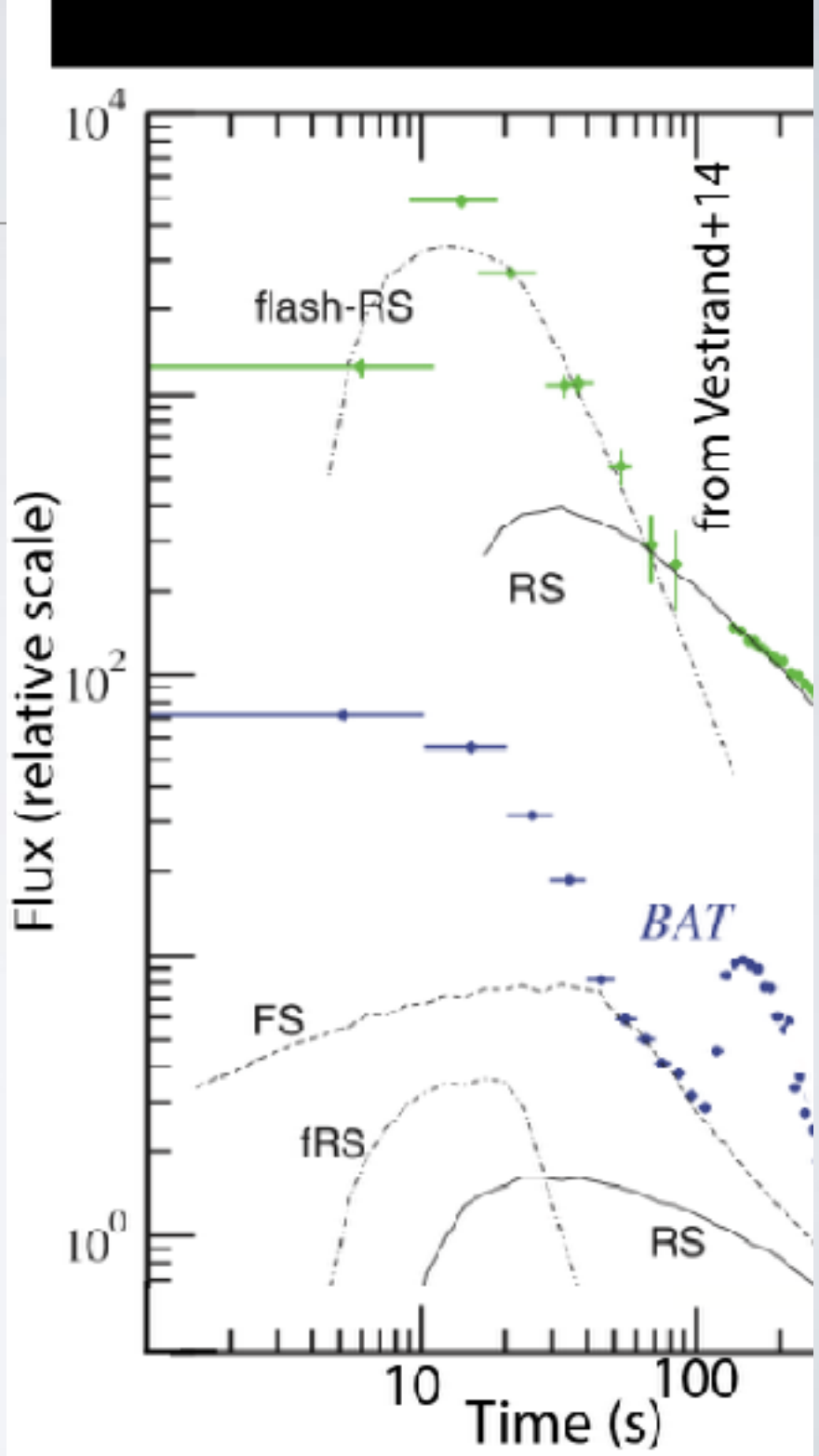
What about in here? Fall steep or shallow?

Just one optical point, doesn't fit!!!

GRB130427A

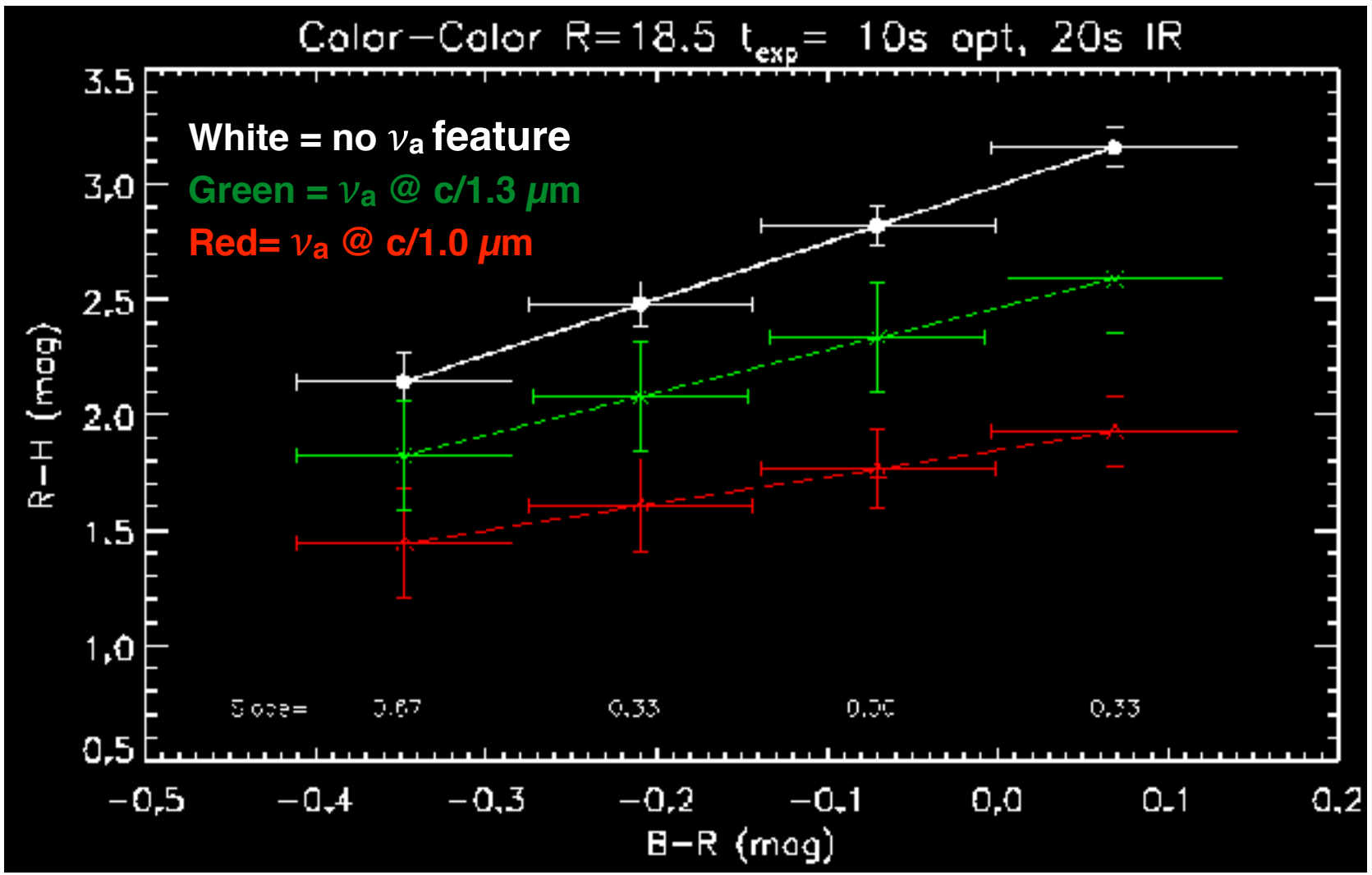
- ***Un***correlated γ, Opt
- Opt >> γ (same as 080319b)
- Vestrand+14: **Reverse Shock** dominates first ~ 50s (shock propagating backwards toward jet origin; decay slope –1.7)
  but… non-unique fit , several parts not fit.
- ==> baryon-dominated jet
  (reverse shock traveling into a magnetic jet produces weak Optical*)
- Note optical spectrum not available to confirm!



* Zhang & Kobayashi 2005; Narayan et al. 2011; Giannios et al. 2008

Color-Color gives Slope, ν_a

- Different slopes separate well on color-color plane
- If between our bands, break frequency, ν_a, determined.



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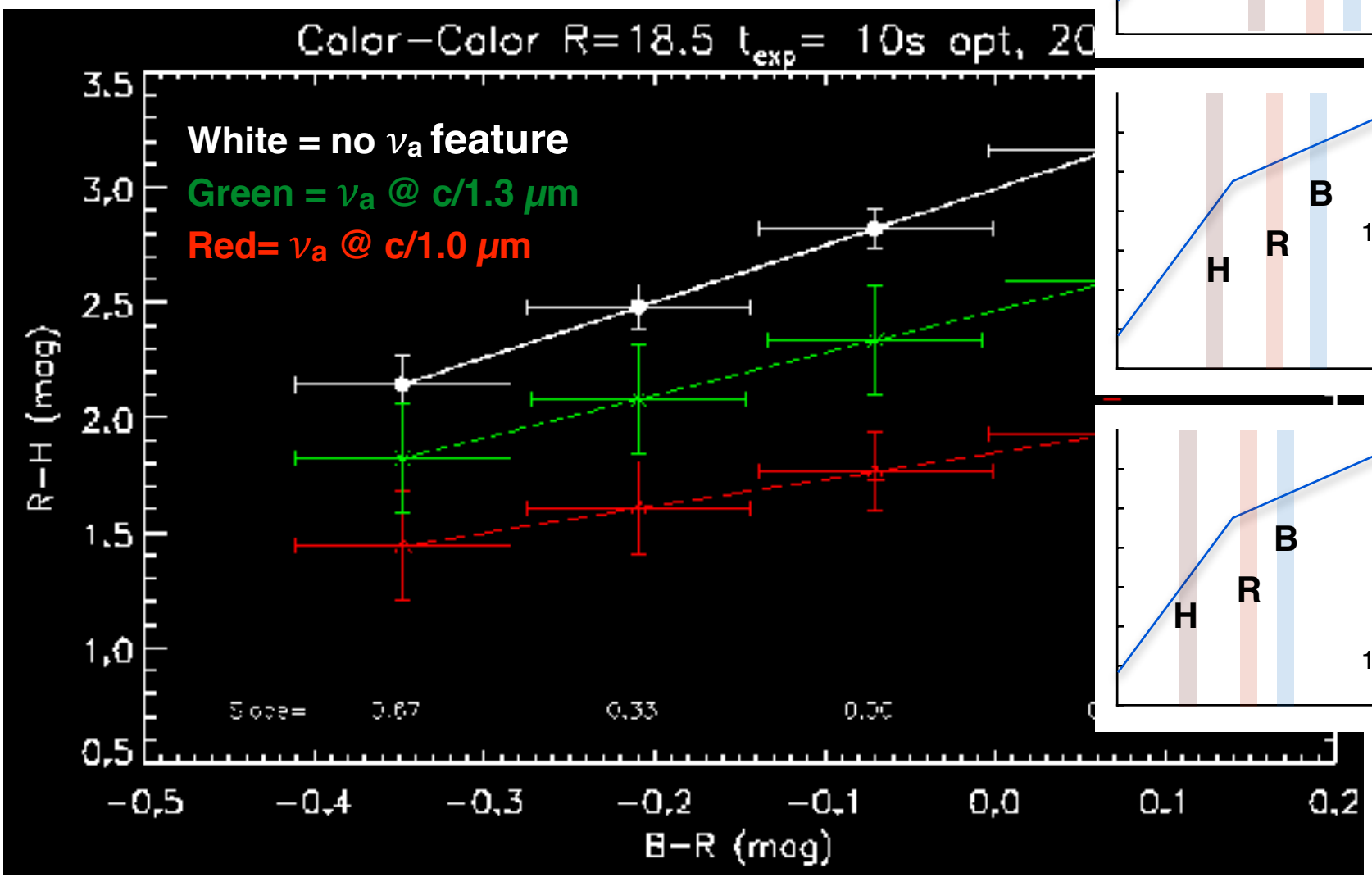

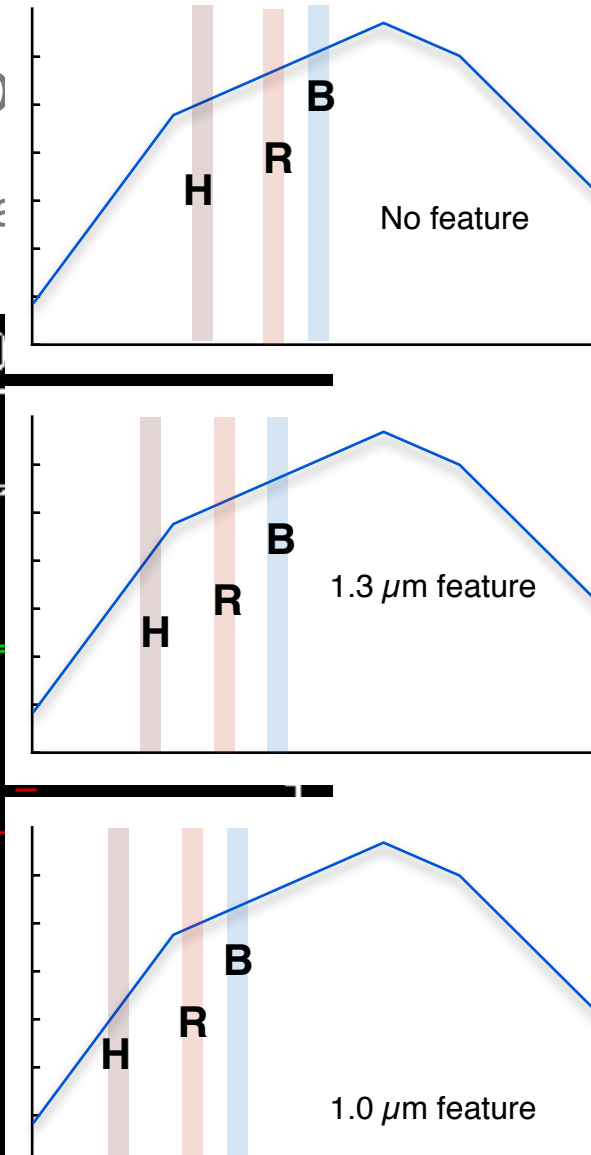

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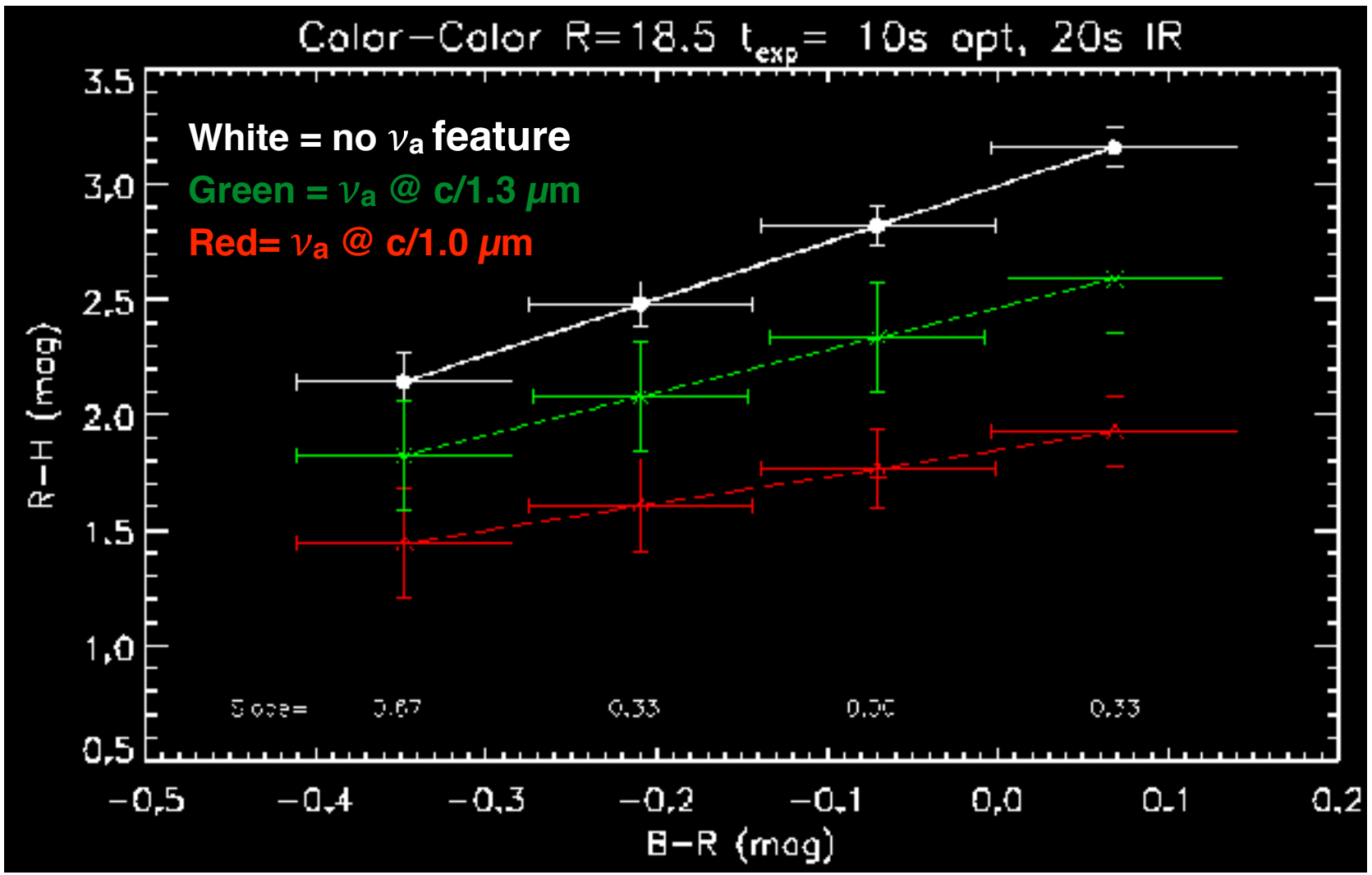

MOST GRBs Extinguished!

- Most GRBs have little optical emission (30/77 UVOT)
  - BUT VIRTUALLY **ALL** GRBs HAVE IR EMISSION[1]
- Median extinction A_V~0.35 mag[2]; range 0.5 - 5 mag[1]

- If you cannot study extinguished GRB, you may have some kind of bias against the most active star-forming regions
- If you **can** detect extinguished GRB, **you will detect many more, ~ 1.6X more than UVOT[3]!**

1 - Perley et al. 2009; 2- Covino et al. 2013; 3-Grossan et al. 2014,